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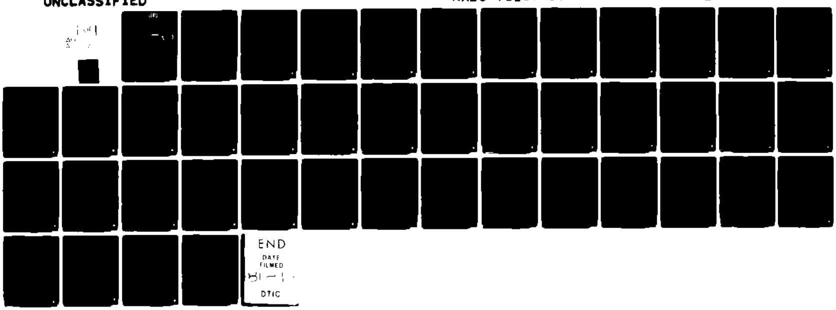
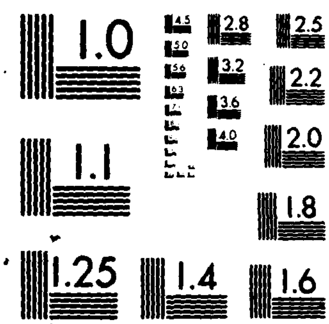
ACOUSTIC FUEL QUANTITY MEASUREMENT SYSTEM. SIGNAL CONDITIONING --ETC(U)
MAY 80 B D KELLER, C R MAYER, B BLANTER N62269-78-C-0433
UNCLASSIFIED NADC-78187-60 NL





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ACOUSTIC FUEL QUANTITY MEASUREMENT SYSTEM·

SIGNAL CONDITIONING UNIT-[redacted]

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This report summarizes work performed by the General Electric Company on contract N62269-78-C-0433 to design, fabricate and test a fuel quantity Signal Conditioning Unit. This equipment was designed, fabricated, integrated with other components and tested on schedule. The results of the test program demonstrates that the concept of using a microprocessor to compute fuel mass to Class III gauging accuracies, based on inputs from linear acoustic probes and a densitometer, is valid.

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SUMMARY

The Naval Air Development Center awarded Contract N62269-78-C-0433 to the Aerospace Instruments and Electrical Systems Department of the General Electric Company to design, fabricate and test a Fuel Quantity Signal Conditioning Unit, in accordance with GE unsolicited proposal MP78-13, dated May 3, 1978 to NADC. This Signal Conditioning Unit is to operate with a quantity of four (4) each 8TJ128 Acoustic Liquid Level Sensors, one (1) each 8TJ129 Densitometer, and an 8KE108 Interface Electronics Unit, for measuring fuel in an A2412 Tank. The type numbered items were procurred by NADC under purchase order N62269-78-M-6772 and loaned to General Electric for the purpose of this contract. The purpose of the Signal Conditioning Unit is to assess the application of acoustic sensors to aircraft fuel quantity systems.

In Phase I of this contract, an algorithm was developed to be used by the Signal Conditioning Unit to compute fuel mass from the liquid level and density sensor signal outputs. The results of Phase I studies were previously summarized.[1]

In Phase II of the contract (Item 0002), a Fuel Quantity Signal Conditioning Unit was designed, built, and tested, to demonstrate the accuracy, repeatability, and overall feasibility of the Acoustic Fuel Quantity Measurement concept, including the operation of the sensors, and the validity of the algorithms developed in the first phase of the contract. The Signal Conditioning

[1]Acoustic Fuel Quantity System, Phase I Summary Report, Contract No. N62269-78-C-0433 (Item 0001), dated April 15, 1979.

Unit is designed to interrogate the Acoustic Liquid Level and Densitometer Sensors through the Interface Electronics Unit, compute the fuel mass, and display the fuel mass in pounds. In addition, the signal conditioner has the capability of indicating the source of certain errors or failures that might occur in the system, such as sensor interrogation errors, sensor faults, or no fuel conditions. In addition, the Signal Conditioning Unit incorporates the following controls: power on/off, run, halt, stop, and error reset.

Upon completion of the construction of the Signal Conditioning Unit, a test program was completed in accordance with a previously agreed upon Test Procedure and format.

The summary test results show that:

1. The concept of using a microprocessor to compute the fuel mass in a tank by measuring the fuel level with a set of linear acoustic probes and the density with a densitometer is valid, and is now proven.

2. The gauging accuracy observed for the laboratory model of the Acoustic Fuel Quantity System exceeds MIL-G-26988C, Class III Gauging, ($\pm$0.5% of full scale, $\pm$1% of indicated) within a pitch and roll envelope of $\pm 10^{\circ}$.

The detailed results of the test program are described in the main body of this report.

The Acoustic Fuel Quantity System Operating Instructions are given in Appendix A.

TABLE OF CONTENTS

LIST OF FIGURES

I. INTRODUCTION AND EQUIPMENT DESCRIPTION

The Acoustic Fuel Quantity System (AFQS) which was assembled and tested under this contract was used as a laboratory test model to demonstrate the viability of measuring fuel mass using acoustic sensors. This concept of using acoustic sensors is to be extended later to an aircraft application for subsequent evaluation in a airborne environment.

The completed AFQS is shown in Figure 1. It consists of the following items:

Four Acoustic Liquid Level Probes (8TJ128)

One Densitometer (8TJ129)

One Interface Electronics Unit (8KE108)

One Signal Conditioning Unit (A2426)

One Test Tank (A2412)

For the Phase II Task reported herein, the system operation is controlled by the Signal Conditioning Unit (SCU). The SCU interrogates the liquid level sensors and the densitometer through the Interface Electronics Unit (IEU). From the fuel height data and the tank geometry, the fuel volume can be determined. Once the fuel volume is known, the fuel weight can be computed by multiplying by the specific weight of the fuel which is determined from the densitometer measurement.

The Acoustic Liquid Level Sensor is shown in Figure 2. The sensor generates a time delay output signal where the delay time is directly proportional to level of the liquid (or fuel) being measured. Scaling of the signal is approximately 300 μsec for 18 inches of unimmersed sensor. The sensor is excited by a short burst of a 1 mHz signal. Sensor weight is 0.36 pounds.

Densitometer

The 8TJ129 Densitometer sensor is shown in Figure 3. The sensor generates a variable frequency which is a function of fluid density. Scaling of the signal output is approximately 5 Hz for a 1% change in the specific gravity. The output frequency for a fuel density of 0.75 is 4429 Hz. Densitometer weight is 0.35 pounds.

Interface Electronics Unit

The electrical signals which drive the sensors are furnished from the Interface Electronics Unit (IEU)(shown in Figure 4). The IEU also takes the raw sensor data and converts it to a digital format suitable for processing in the SCU. The operation of the IEU is started upon command from the Signal Conditioning Unit (SCU). A byte from the SCU is received at the Universal Asynchronous Receive/Transmit (UART) chip indicating which of the Acoustic Liquid Level Sensors (Channels 1 through 4) or Densitometer (Channel 5) is to be interrogated.

In the situation where one of the Acoustic Liquid Level sensors is to be interrogated, the control byte performs three functions:

1. It selects the channel in question through the multiplexer;
2. It selects the 1 mHz clock option;
3. It initiates a "start" pulse.

The "start" pulse initiates the electrical drive pulse on the Acoustic Liquid Level transmit waveguide, and triggers a flip-flop which, through the multiplexer, starts the scaler counting 1 mHz pulses. When the signal from the Acoustic Liquid Level sensor is received, it is amplified and detected, and stops the scaler counting by setting the flip-flop in the opposite state. The output of the scaler is then read into the UART as two 8 bit digital words which will be combined later in the

SCU to represent the time delay between the transmit and receive pulses, in microseconds. The two 8 bit words are transmitted back to the Signal Conditioning Unit over the serial line. The interrogation sequence is repeated every 10 milliseconds.

For Densitometer interrogation, the period timer is gated on for thirty-one densitometer periods. The timer is synchronized by starting the gate at the end of the first densitometer period, then counting through the next 31 periods. The scaler counts clock pulses as directed, but a 2 mHz clock is counted rather than a 1 mHz clock, in order to increase the resolution.

Signal Conditioning Unit

The Signal Conditioning Unit, which is the hardware developed under this project, is shown in Figure 5. The SCU consists of an Intell 8086 microprocessor, an input/output data port (UART) which is used to pass data back and forth between the SCU and the IEU, a memory, a display, and a keyboard. The UART, memory, and display control ports are addressable, and data can pass between these functional areas of the SCU as shown in the SCU block diagram in Figure 6. Keyboard operation, however, requires a special operating mode, where PROMS with a keyboard monitor program are substituted for the PROMS containing the operating system. This substitution technique is described in Appendix A, Acoustic Fuel Quantity System

Operating Instructions." The Signal Conditioning Unit is implemented by using an Intel SDK-86 board which contains all of the above mentioned components. It was programmed using the high level PLM-86 language and integrated into the hardware using the Intel development system. The software organization is shown in Figure 7. The program is controlled by an executive module. It controls not only programming but timing functions. When the power is turned on, the SDK-86 system automatically resets the program sequence so that it starts at the first instruction of the executive software module. The executive software module first calls the input data and sensor control module. The input data and sensor control module interrogates the four Acoustic Liquid Level Sensors and the Densitometer sequentially through the UART. The return data is the liquid level or densitometer data from the sensors. The executive module then calls the module error/check. The data is examined in this module to determine if there are any out of range or transmission errors. If no errors are detected, or no more than one Acoustic Liquid Level Sensor is found operating out of range, the executive module then calls the mass computation module where the fuel mass is computed, based on density and fuel height data as well as the stored configuration information.

The mass computation takes place in several steps. First, the acoustic liquid level probe height data, which at this stage is in micro-seconds, is restated in terms of inches by the formula:

Fuel Height (in inches) = 18.31 -.06337 x (probe time delay in micro-sec)

The constant term accounts for both the fact that the height is measured from the bottom of the tank rather than the top, and that there is a fixed time delay due to the propagation time across the gap between the sensor waveguides.

The next step in the computation is the determination of the liquid surface plane. The coefficients of the plane are found from the formulae:

$$A = K_1 \times (FH_2 - FH_1) + K_2 \times (FH_2) + K_3 \times (FH_3)$$

$$B = K_4 \times (FH_2 - FH_1)$$

$$C = K_5 \times (FH_3 - FH_2)$$

FH_1, FH_2, FH_3 are fuel heights in inches at probes 1, 2, and 3, respectively.

The constants K_1 through K_5 are determined by the tank geometry and the probe location. In normal operation, these constants are:

$$K_1 = 1.16665$$

$$K_2 = -.01801802$$

$$K_3 = -.148649$$

$$K_4 = .037037$$

$$K_5 = .027027$$

These constants change under conditions where a system configuration change is necessary, such as, when one probe is operating out of range

(which will be discussed shortly). The coefficients A, B, C, then allow the fuel plane to be determined from the equation:

$$Z = \text{Fuel plane} = A + Bx + Cy$$

where the coordinate system is centered at the corner of the tank corresponding to probe #1, and where x corresponds to the width direction and y to the length direction in the tank. The coordinate system is shown in Figure 9.

As described in the Phase I final report, Reference I, the tank is divided into 400 primitive integration elements, 2.4" x 2.4", whose height is determined by the height of the fuel plane, as given in the previous equation. The resulting volumes are summed to give the total tank volume from the formula:

$$\text{Volume} = \sum_{M=0}^{399} (2.4'' \times 2.4'' \times \text{height of integration element})$$

The fuel mass is then computed by multiplying volume by the specific weight of the fuel which has been translated from the count generated in the Interface Electronics Unit (IEU) by the fomula:

$$\text{Specific weight of fuel (in lbs/in}^3) = -.183328 + .0000150346 \times (\text{densitometer count from IEU})$$

When the fuel mass has been computed, the data is displayed by having the executive module command the display port control module to perform this function. The computed mass is displayed in a four character data field, as shown in Figure 8. There is also a four character

error code field which indicates various error conditions should they arise, and these are summarized in Table 1. These errors are found by the error check software module. They fall into the category of "out of range" or "parity/framing" types of errors, and the computations proceed differently depending upon the type of error found. If parity and framing errors, i.e., communications errors, are discovered, the executive module requests that the previous mass values be displayed (along with the appropriate error code), and the program recycles back to the initial instruction in the program sequence.

The "out of range" condition can cause the system to respond in different ways. For a single acoustic liquid level probe failure, i.e., "out of range" condition, the system is reconfigured in the reconfiguration submodule of the error-check module. This is done by selecting the outputs from the remaining three probes, and proceeding to compute the mass as in the case when there were no errors found, except that the appropriate error code would be displayed. In this case, the constants used in computing the fuel plane are different than those shown above. When more than one level sensor is "out of range," the executive routine causes the display port control module to display the appropriate error code, as well as the previously computed mass value, after which the program is re-started.

Densitometer out of range conditions cause either the previous density value to be used when computing fuel mass, or, if the densitometer operation were out of range when the system was turned on, an average

mass value would be used. Other possible error or fault conditions are indicated in Table 1, along with the error and mass field displays. The rationale used in defining these outputs is simply an extension of that given in previous paragraphs.

For normal system operation, after the mass is displayed, a five second time delay is initiated in the executive module and then the program is returned to the first instruction. Of course, this is not done when the mass computation is not performed as when several system faults occur. The detailed software design of the SCU is documented in the General Electric specification per Reference 2.

The remaining item in the AFQS is the test tank. It is of welded aluminum construction and is shown in Figure 9. The tank dimensions are 48" x 48" on top, 36" x 48" on the bottom, and the tank is 18" high. The sensor locations are also shown in the Figure. There are four ports on the top of the tank to provide access to the probes, the densitometer, and the interconnecting cables. An external fuel level sight gauge is provided.

TABLE 1

DISPLAY OUTPUT

Operating Condition	Display Error Field	Display Mass Field
1. No Error	0123*	Mass Value
2. Parity Error, Liquid Level	"P" In Channel Position	Previous Mass Value
3. Framing Error, Liquid Level	"E" In Channel Position	Previous Mass
4. Single Liquid Level Sensor Failure	"F" In Channel Position	Mass
5. Multiple L.L. Sensor Failure	"FF" In Channel Positions	Previous Mass Value
6. Densitometer Error		
a) during operation	"DD" In Left 2 Error Fields For Count < 13K "DD" In Right 2 Error Fields For Count > 17K	Estimated Mass
b) at system turn-on	Same As Above	Estimated Mass
c) transmission error	R	Previous Mass Value
7. Single Liquid Level Sensor Failure and Densitometer Failure	Display As Shown Below Possible Display Outputs F D - - D F - - Densitometer - D F - Count < 13K - D - F F - D - - F D - Densitometer - - F D Count > 17K - - D F	Estimated Mass

* Channel positions 0, 1, 2, 3 Correspond to sensors 1, 2, 3, 4

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II. SYSTEM TEST RESULTS

The Acoustic Fuel Quantity System was tested in accordance with General Electric Test Procedure No. 2H1030-14, dated 29 June 1979, as submitted to NADC per Exhibit B of CDRL, Item A002. These tests were performed over a period from 1 December 1980 through 21 December 1980 in the fuel quantity laboratory at the General Electric facilities in Wilmington, Massachusetts.

In a series of tests performed on the system, it was established that Class III gauging accuracies can be met and exceeded through the concept of using the Acoustic Liquid Level probes, a Densitometer, and the developed algorithms for the computation of fuel mass.

Test Setup

The tank, electronics, instrumentation, and pumping apparatus were configured in the laboratory as shown in Figure 10. Means for raising and lowering the tank consisted of a chain-fall, the top of which was attached to an overhead gantry and the bottom of which was connected at one point to four cables which harnessed and supported the tank. Specific pitch and roll angles were achieved by placing calibrated blocks between one bottom edge of the tank and the floor, and resting the tank on the blocks. A load cell accurate to plus or minus one pound, up to a 1,000 pound load was placed in tension between the chain-fall and the four-cable harness which together support the tank assembly. With an empty tank and with all electrical cables carefully draped from the internal sensors to the bench mounted electronics, the tare weight of the tank, sensors, and support harness indicated by the load cell readout was 241 pounds.

This weight is subtracted from gross weight to obtain net fuel weight in all tests.

A pump and several storage drums were used to add and subtract fuel from the tank. All tests were run at ambient laboratory temperature (55^{o} to 70^{o}F), and at the prevailing pressure and humidity. The liquid used in all the tests was MIL-L-7024 Type II.

Results

Data sheets containing all tests results are shown as Figures 11 through 14. For purposes of calculating error as a percent of full scale, the full scale fuel weight was taken as 1,000 pounds.

1) Scale Error - Figure 11

Maximum Scale Error	5# or .5% F.S.
Average Scale Error	-.2# or .02% F.S.
Standard Deviation of Error	2.9# or .29% F.S.

2) Attitude Error - Figure 12

Range of Attitude	$\pm 10^{o}$ Pitch and $\pm 10^{o}$ Roll
Range of Fill	80% to 20%
Maximum Error	-10# or 1% F.S.
Average Error	1.7# or .17% F.S.
Standard Deviation of Error	3.5# or .35% F.S.

NOTE: Some of the data points were omitted because the combination of steep pitch and roll and fullness caused either the fuel to slosh out of the tank (i.e., 80% full, $\pm 10^{o}$ pitch and $\pm 10^{o}$ roll) or more than one probe to be out of the liquid (i.e., 20% full $\pm 10^{o}$ pitch and $\pm 10^{o}$ roll). At lesser angles and at 50% full, valid data was taken.

3) Open Probe Test - Figure 13

Maximum Error	-6# or -.6% F.S.
Average Error	-1.9# or -.19% F.S.
Standard Deviation of Error	3.5# or .35% F.S.

In all cases where a probe was failed, the letter "F" appeared in the correct error field to indicate such.

4) Acoustic Noise Test - Figure 14

Hammer flows on the tank had no effect on the accuracy of the Acoustic Liquid Level Sensors or densitometers.

Discussion of Results

Error Sources

There are four independent error sources that cause the difference between the fuel masses indicated by the load cell and the fuel quantity processor:

Load Cell

Densitometer

Software

Acoustic Liquid Level Sensor

Each contributes to total system error in varying degrees as explained below:

The load cell readout was to the nearest pound and thereby contributed as much as 0.1% the full scale error. When looking for accuracies as close as 0.5% full scale one can justify the need for at least .05%

or ½ pound readout resolution. Load cells of this accuracy over the 1000 pound range were not available for this test.

Densitometer accuracy was excellent for all tests and contributed only 0.13% full scale error (1.3 pounds). The resolution of the Densitometer was one in 14,000 and was, therefore, not a significant error contributor. The slight difference between actual and computed density is a result of accuracy of the hydrometer used to calibrate the Densitometer. It was readable to 0.768 ± .001 specific gravity. The Densitometer was calibrated to within ±1% over a wide range of densities but was within 0.13% in the range where the tests were performed.

The computer program which calculates volume of the fuel can introduce up to 5.7 pounds error (.57% F.S.) depending upon the attitude and height of the fuel plane. As shown in Figure 15 this comes about because the integration routine assumes a step-sided tank where the walls slope 3 to 1. This error can be reduced by integrating a finer mesh of columns at the expense of longer computation cycle time.

Probe errors of one percent (0.18") in combinations can lead to system errors anywhere between one percent (10#) to no error at all depending on the sign of the error of the three liquid levels that describe the liquid plane. Figure 16 shows four different cases of how an individual probe error of 1% affects the overall system accuracy. The tests reported herein demonstrate that probes having one percent accuracy can act together to give a system accuracy better than one percent.

III. CONCLUSIONS AND RECOMMENDATIONS

In all cases, the Acoustic Fuel Quantity Measuring System demonstrated in the laboratory exceeded Class III fuel gauging accuracy requirements ($\pm \frac{1}{2}$% full scale; $\pm$1% indicated) by wide margins Thus, the concept of obtaining highly accurate fuel gauging using data from a Densitometer and a set of linear Acoustic Liquid Level sensors has been confirmed.

In light of these conclusions a comprehensive program has been proposed to pursue the goal of developing and accomplishing a flight evaluation of a Class III fuel gauging system using the AFQS concept. This program has been documented in the proposal "Acoustic Fuel Quantity System Development Plan Proposal," General Electric document MP79-40B, dated November 26, 1979 submitted to NADC and NAVAIR for review.

This program was divided into three phases. The tasks are identified as follows:

Phase One Tasks:

1. Evaluating system operation under dynamic environments.
2. Developing improved system algorithms.
3. Constructing prototype equipment.

Phase Two Tasks:

1. Perform environmental, hazard, and electromagnetic compatability tests.
2. Perform certain system design tasks, such as system self-test, and system interface studies.
3. Prepare Acoustic Fuel Quantity System specification.

Phase Three Tasks:

During the proposed third and final phase of the program, flight evaluation preparation, testing, and system acceptance tasks are to be completed.

At the completion of these tasks, sufficient flight testing and system evaluation would have been completed to demonstrate the system performance in a real world environment.

Acceptance by the U.S. Navy of the proposed development plan for the Acoustic Fuel Quantity System would result in a plan involving DDT&E tasks for a fuel mass measurement system which could be applied to all new transport, fighter, and helicopter aircraft. The development plan spans a period of three (3) years for the three (3) phases identified above.

General Electric has continued the development of the Acoustic Liquid Level Sensor and Densitometer with internal funds since the completion of the NADC Signal Conditioning Unit contract. The internal effort included investigating and designing an acoustic probe assembly which would meet the application environments and be configured for best producibility. At this time, a number of redesigned sensors have been tested and evaluated. No firm design has been established to date for production.

General Electric is continuing to investigate technology breakthroughs for application to the Acoustic Sensors and mass calculating system, and solicits the U.S. Navy to continue supporting the AFQS program.

As the world emphasis on fuel efficiency and conservation escalates, it will be necessary for new aircraft to incorporate subsystems which can enhance the overall management of fuel. An accurate fuel gauging system to Category III specifications can be a worthwhile functional element in the fuel management architecture. With an accurate airborne fuel gauging system, the flight crew can more reliably determine his minimum fuel load for a given mission profile. This means that the cost to carry an excess margin of fuel would be minimized while at the same time there would be an increase in flight performance as a result of the reduced take-off fuel weight.

Many times mission effectiveness is directly related to the on-station time of the aircraft. A pilot, or the flight crew, must trade-off on-station time for a safe return flight. This trade-off depends on the reliability of the fuel quantity measurement system and the information presented to the pilot. If the system reliability is low, it may be necessary to alter the mission to allow a sufficient margin for error in order to effect a safe return flight. Improvement in fuel gauging to Category III levels would mean more confidence in the fuel status measurements, and thus, maximize the effectivity of the mission.

VSTOL aircraft are particularly sensitive to payload and gross weight. A higher accuracy fuel measurement system, such as demonstrated in the AFQS, can significantly benefit VSTOL operation. General Electric looks forward to achieving a successful flight evaluation with an airborne system for the U.S. Navy.

REFERENCES

1. Acoustic Fuel Quantity System, Phase I Summary Report, Contract Number N62269-78-C-0433 (Item 001), as resubmitted 10/20/79.

2. Software Requirements Document for Acoustic Fuel Quantity System, General Electric Specification Number SW2000-006, dated 9/18/79.

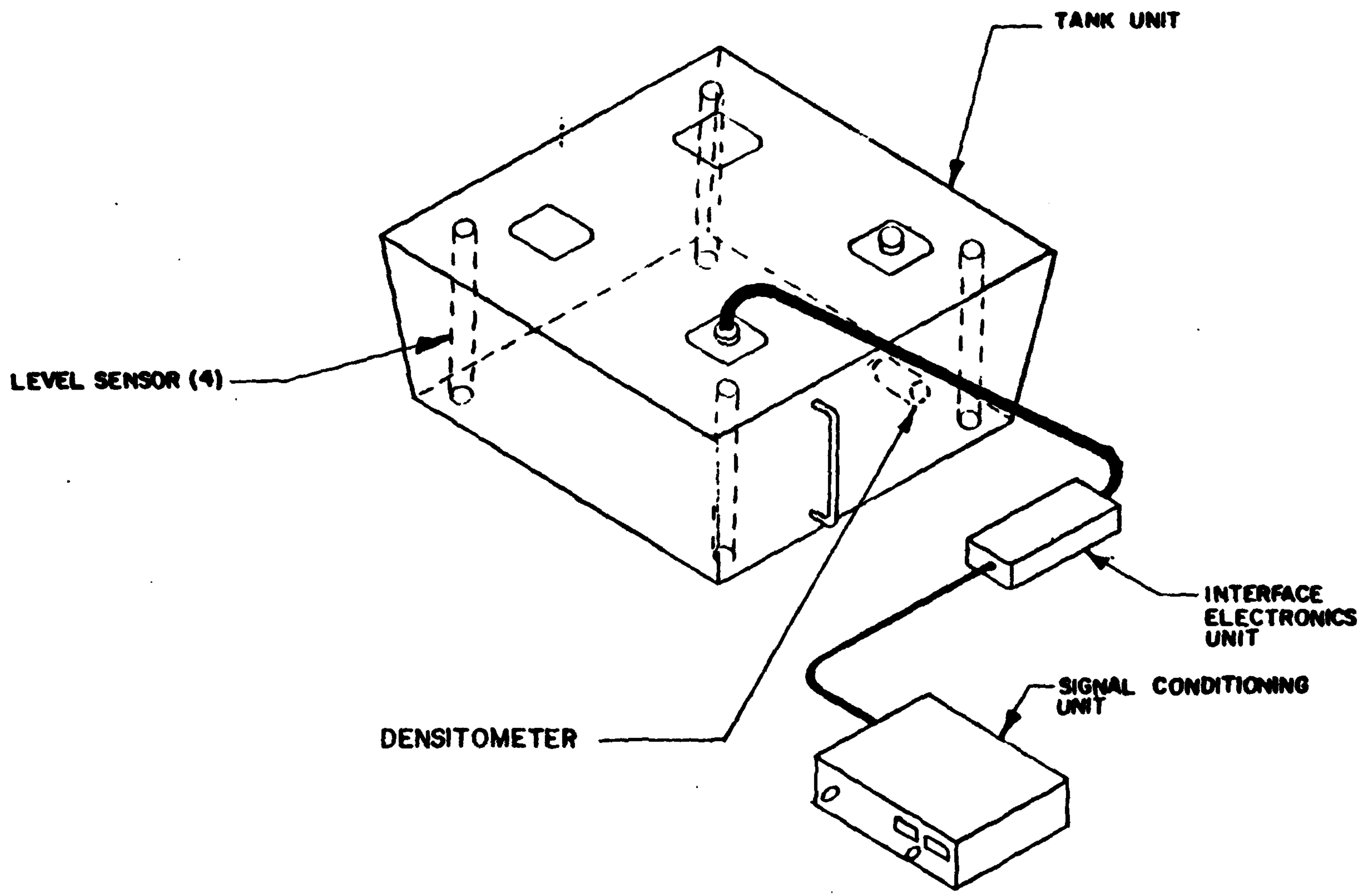


FIGURE 1

ACOUSTIC FUEL QUANTITY SYSTEM FOR NAVY DEMO

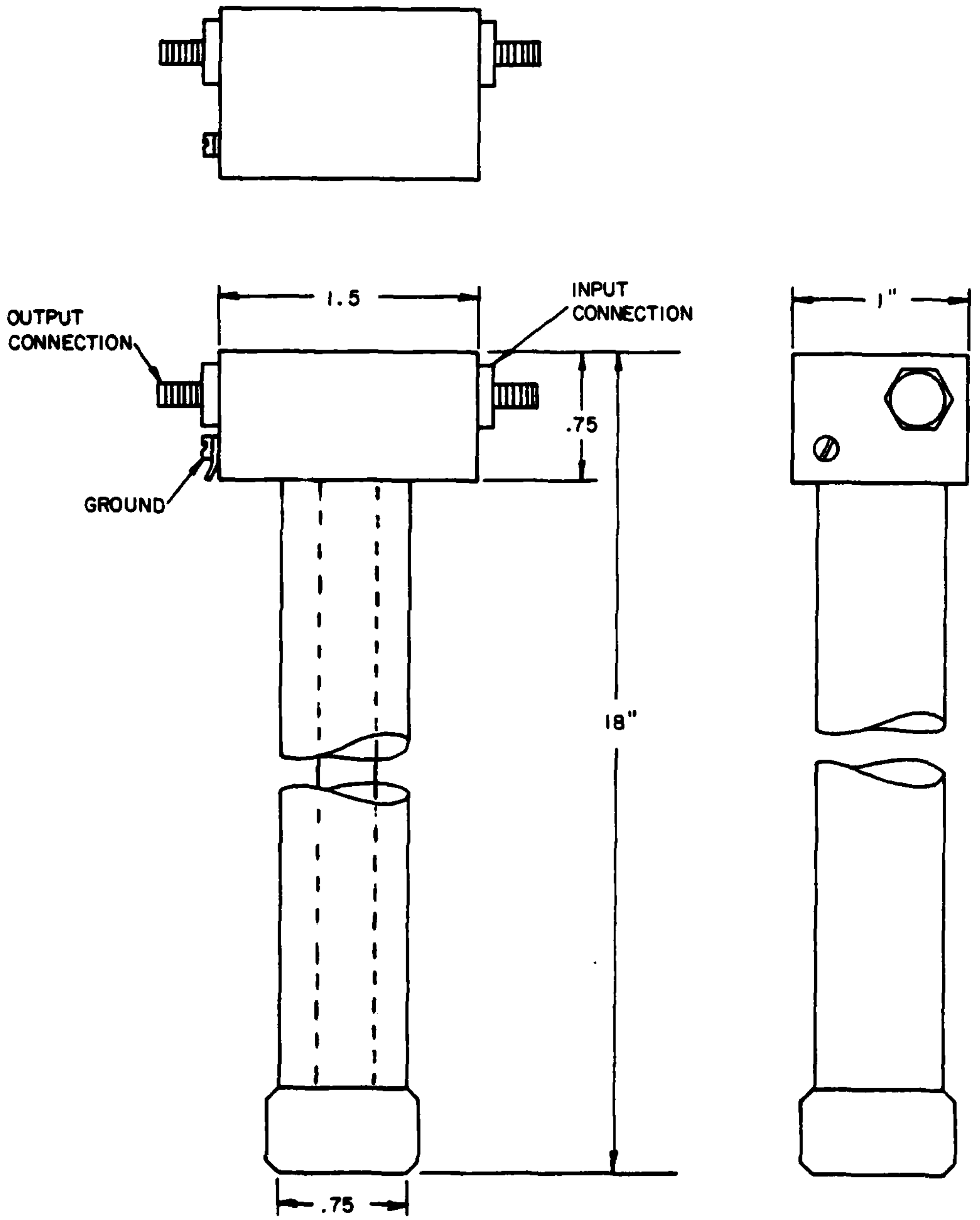


FIGURE 2

8TJ128 ACOUSTIC LIQUID LEVEL SENSOR

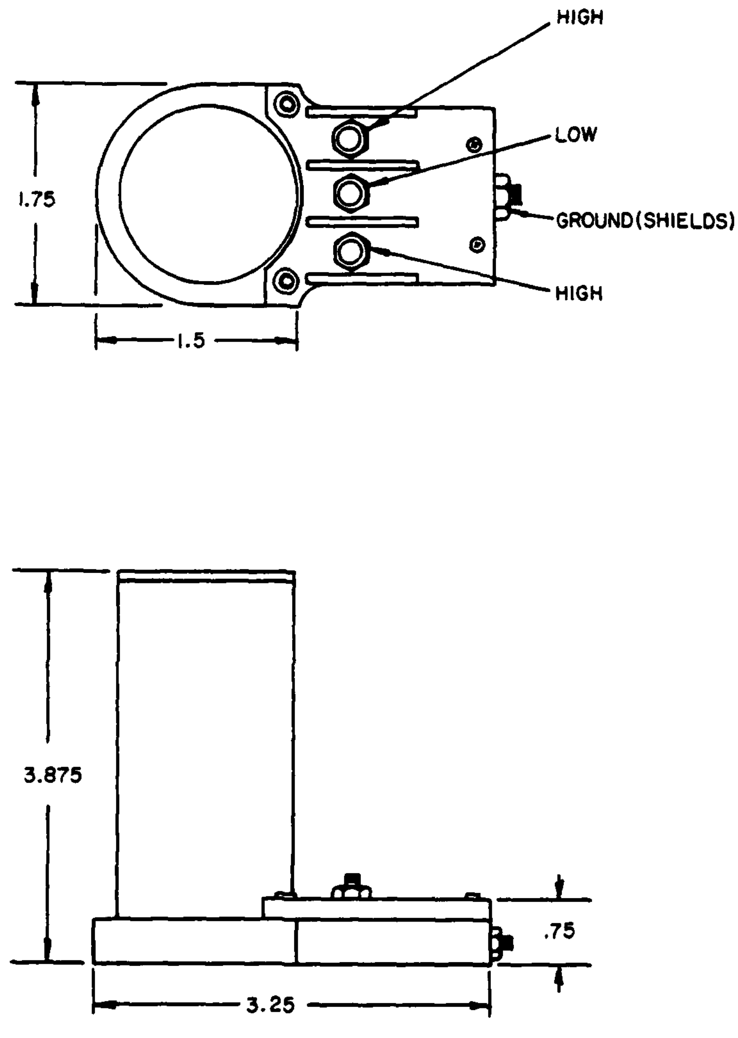


FIGURE 3
8TJ129 DENSITOMETER

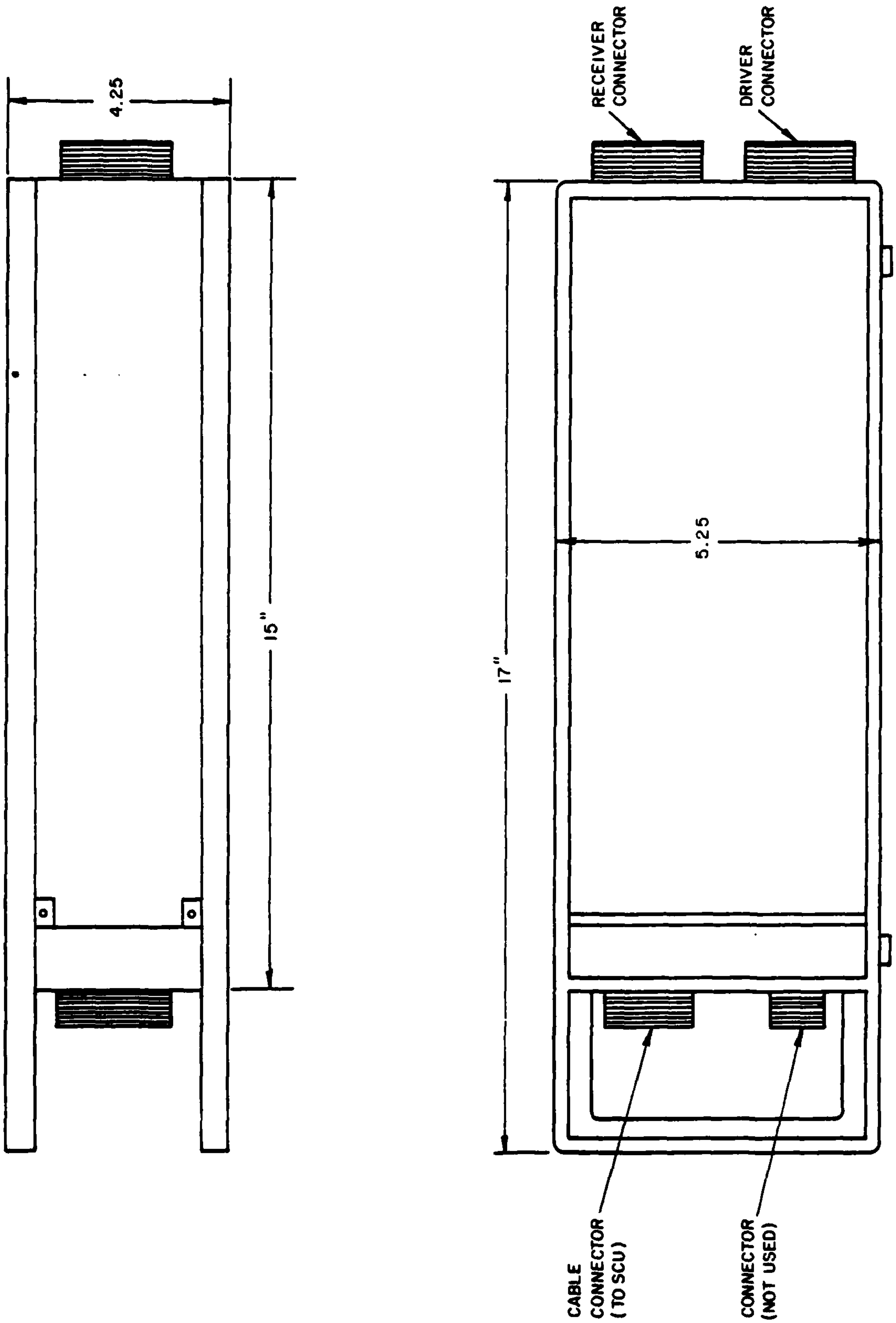


FIGURE 4
8KE108 INTERFACE ELECTRONICS UNIT

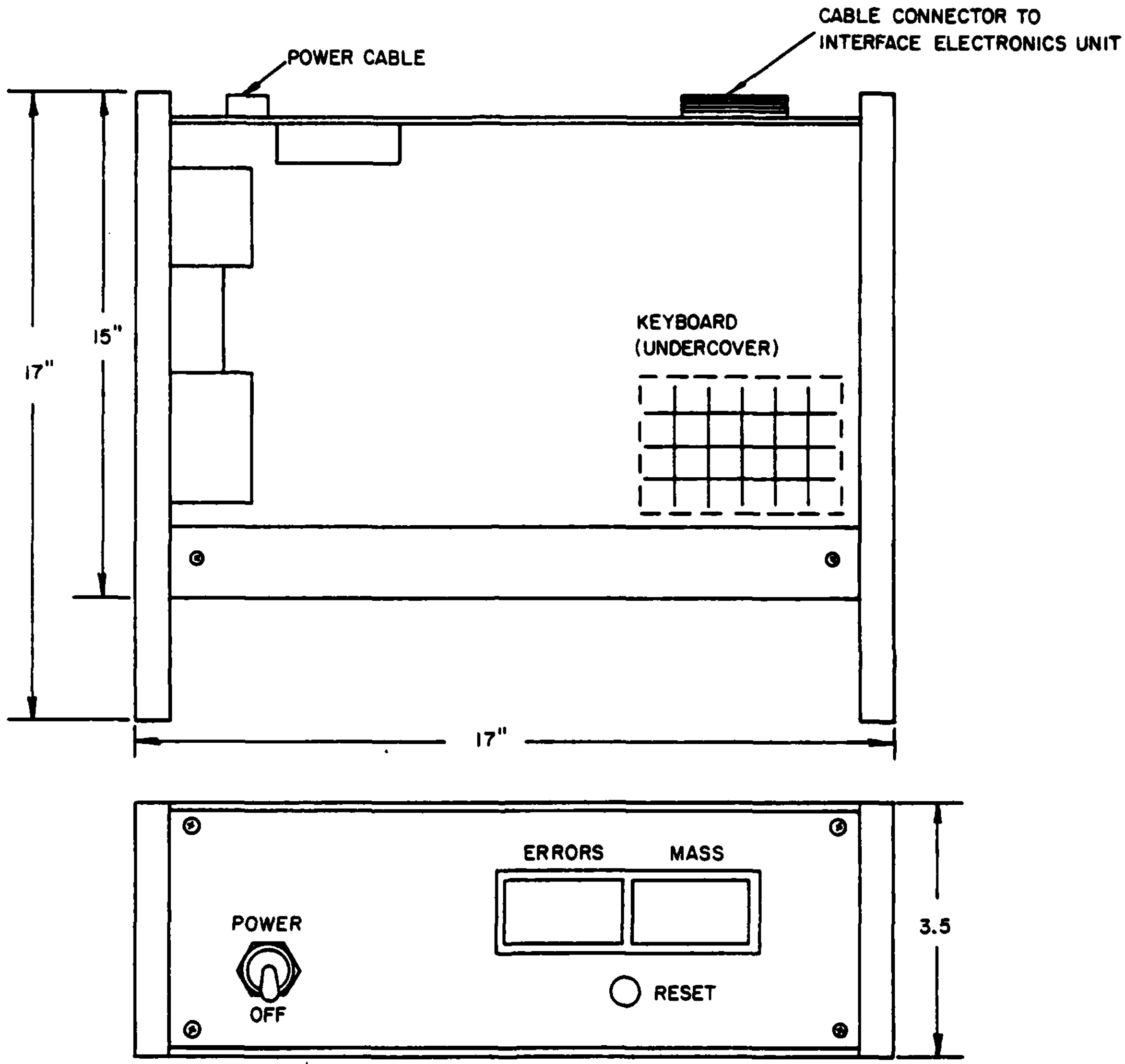


FIGURE 5

FUEL QUANTITY SIGNAL CONDITIONING UNIT OUTLINE DRAWING
(A2426)

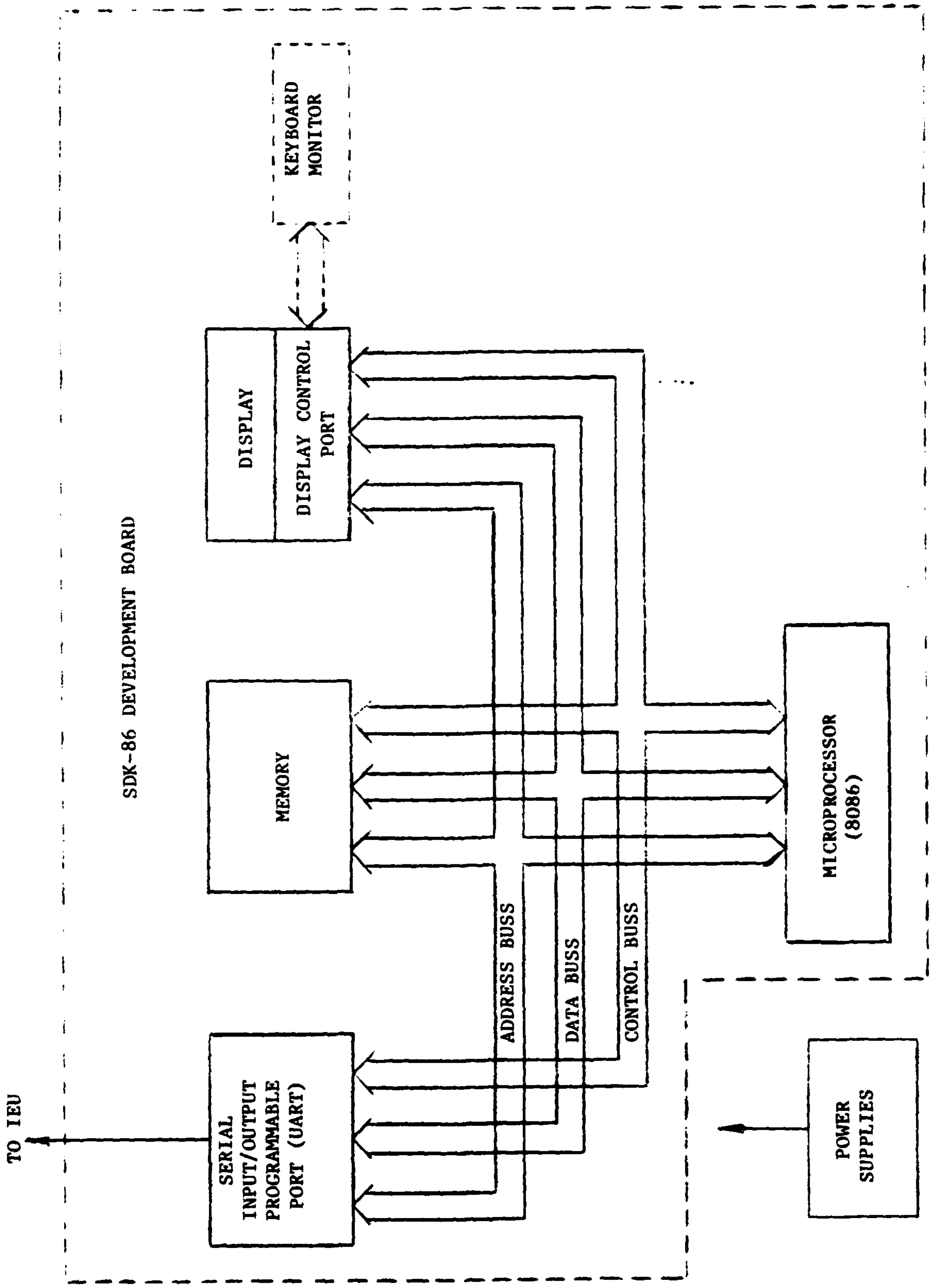


FIGURE 6
SIGNAL CONDITIONING UNIT DIAGRAM

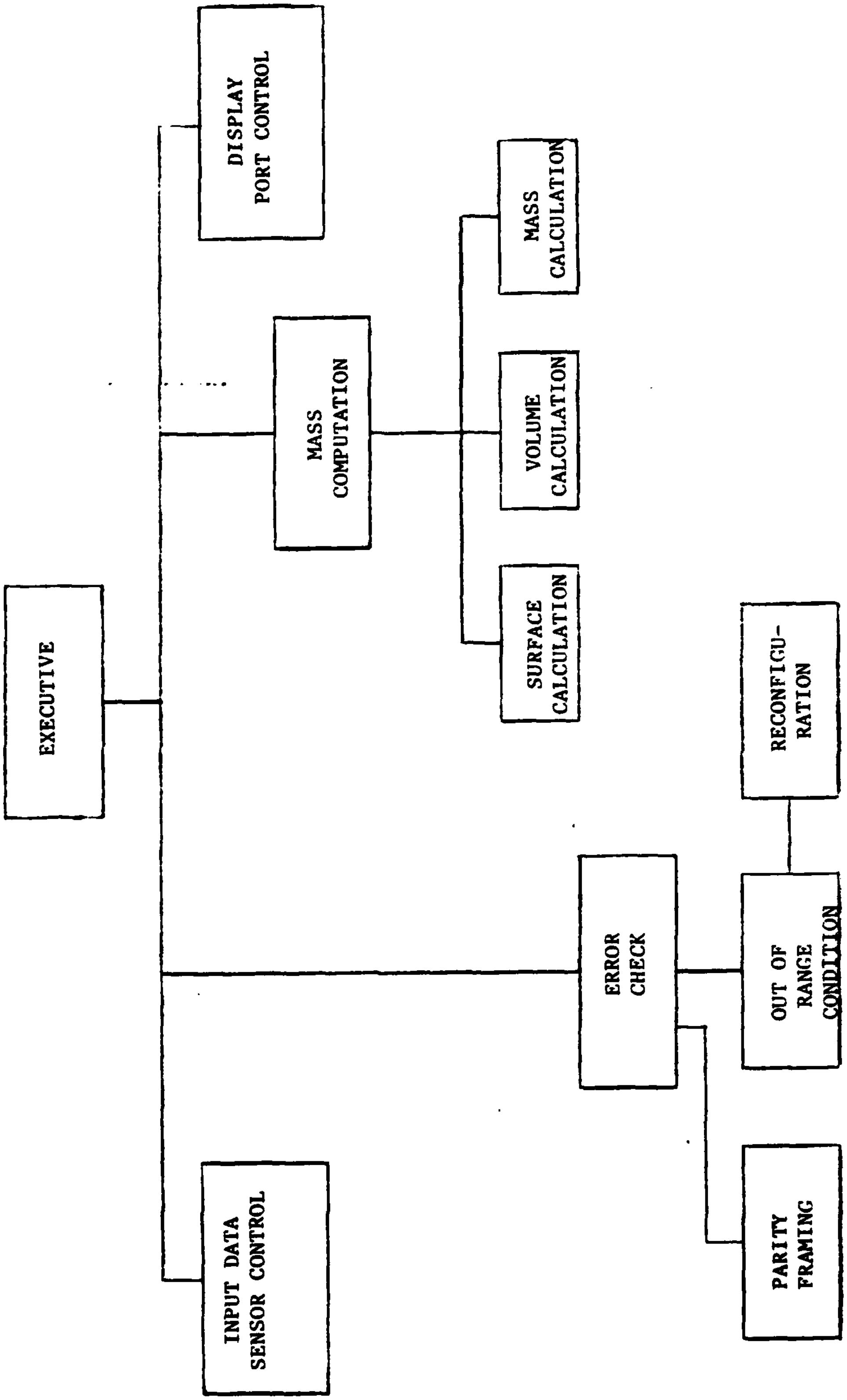


FIGURE 7
SOFTWARE HIERARCHY

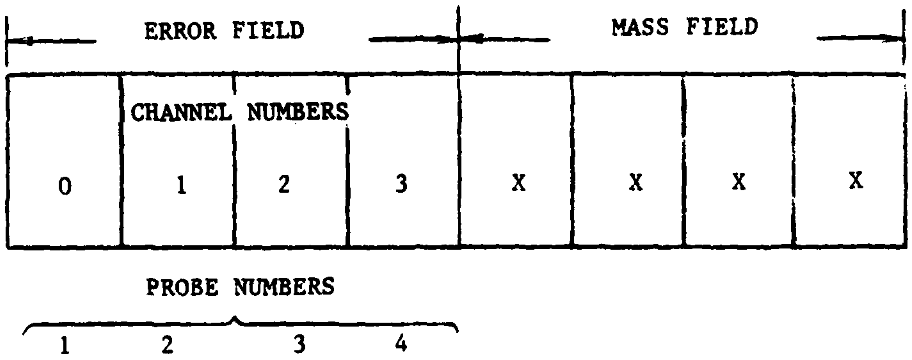
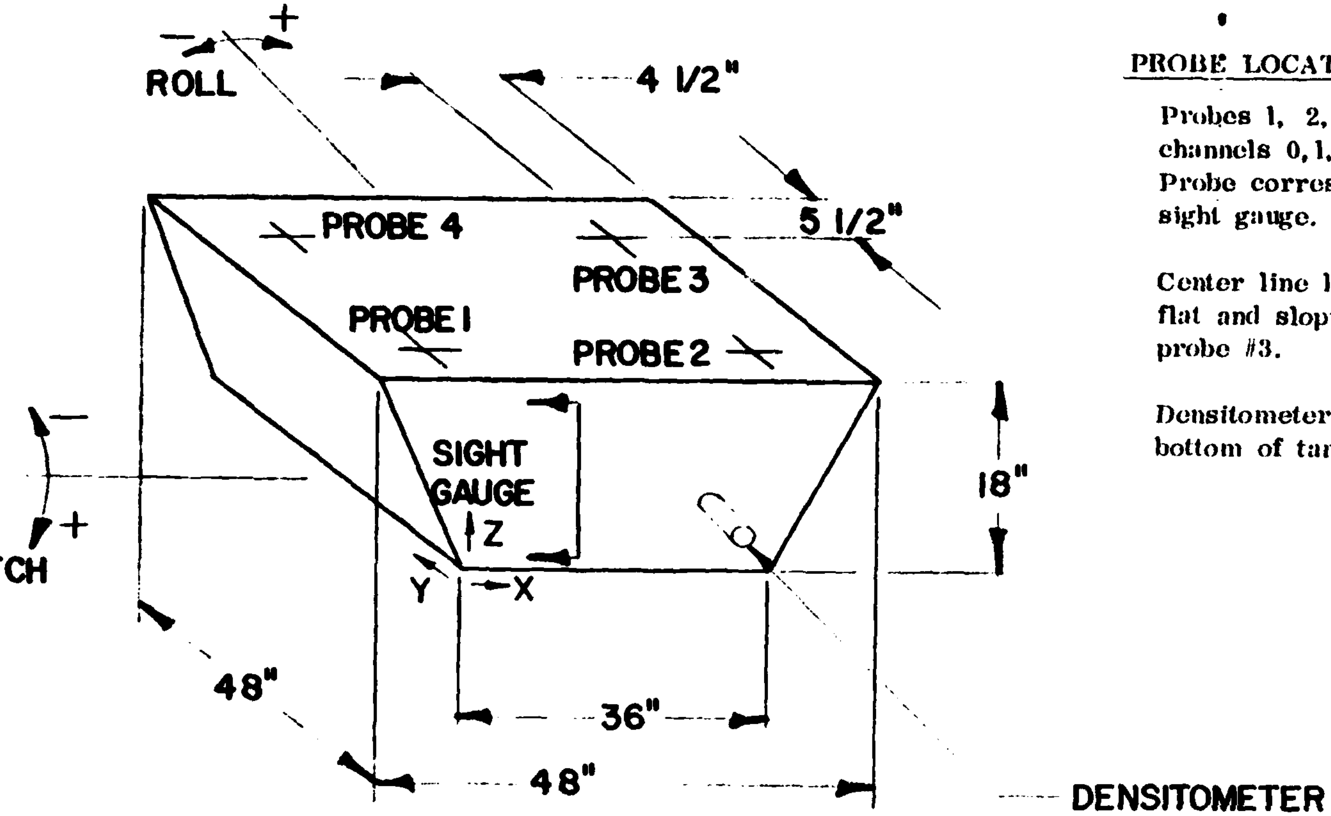


FIGURE 8

DISPLAY FORMAT



PROBE LOCATIONS

Probes 1, 2, 3 and 4 correspond to channels 0,1,2 and 3 as shown in Table 1. Probe corresponding to channel 1 is nearest sight gauge.

Center line locations of probes relative to flat and sloping walls same as shown for probe #3.

Densitometer located near probe #2 at bottom of tank.

FIGURE 9

TANK DETAIL SHOWING DIMENSIONS AND PROBE LOCATIONS

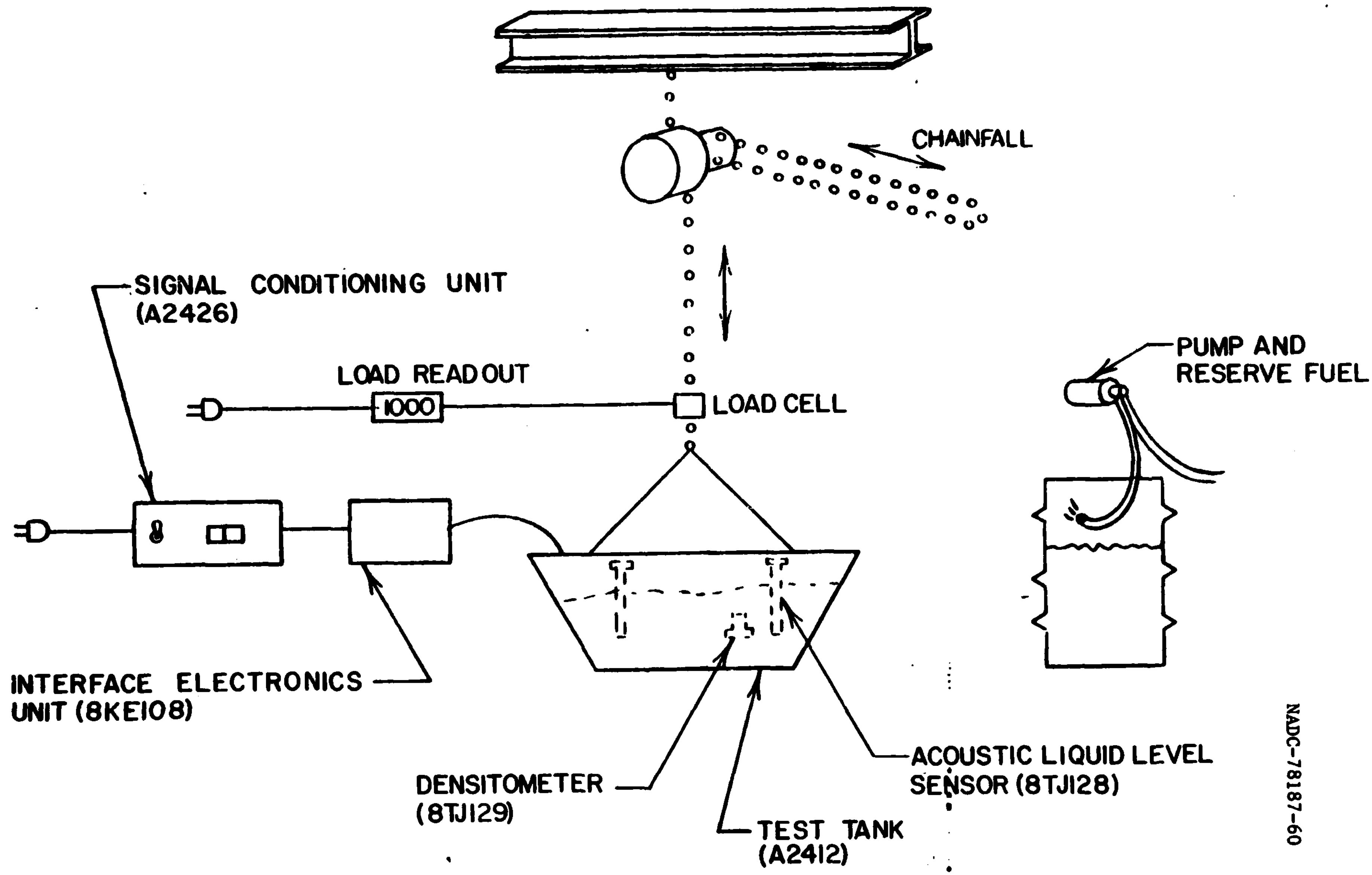


FIGURE 10

TEST SET UP FOR ACCURACY MEASUREMENT

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FIGURE 11

SCALE ERROR TEST

TEST POINT %	LOAD CELL #	TANK #	ACTUAL # Fuel	COMPUTED # Fuel	ERROR #	CLASS III ERROR LIMIT
FULL 90	1115	241	874	871	-3	14
80	1007		766	761	-5	13
70	925		684	682	-2	12
60	803		562	561	-1	11
50	703		462	463	+1	10
40	604		363	367	-2	9
30	485		244	246	+2	7
20	391		150	155	+5	7
10	334		93	94	+1	6
0	304		60	62	+2	6

CAL. FLUID TYPE test oil DENSITY 0.02773 #/in³

AMBIENT TEMPERATURE 20°C

TESTED BY B. Blauter DATE 6. 12. 1979

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FIGURE 12

ATTITUDE ERROR TEST

FLUID TYPE test oil AMBIENT TEMP. 20°c TESTED BY B. Blauster 12.7.79

TEST POINT % FULL	PITCH DEG.	ROLL DEG.	LOAD CELL #	TARE #	ACTUAL # Fuel	COMPUTED # Fuel	ERROR #	CLASS III ERROR LIMIT
80	0	0	925	241	684	682	-2	14#
	0	+10				684	0	
	0	-10				675	-9	
	+10	-10					--	
	-10	-10				-	--	
	+10	+10				-	--	
	+10	0				677	-7	
	-10	0				686	+2	
	+5	-5				679	-5	
	-5	+5				682	0	
50	0	0	738	241	497	498	+1	12#
	0	+10				496	-1	
	0	-10				500	+3	
	+10	-10				492	-5	
	-10	-10				497	0	
	+10	+10				498	+1	
	+10	0				498	+1	
	-10	0				496	-1	
	+5	-5				497	0	
	-5	+5				495	-2	
20	0	0	505	241	264	264	0	10#
	0	+10				265	+1	
	0	-10				264	0	
	+10	-10				254	-10	
	-10	-10				265	+1	
	+10	+10						
	+10	0				263	-1	
	-10	0				266	+2	
	+5	-5				264	0	
	-5	+5				267	+3	

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FIGURE 13

OPEN PROBE TEST

FLUID TYPE test oil

AMBIENT TEMPERATURE 20°C

TEST POINT 50% FULL

LOAD CELL 697 #

TARE 241 #

ACTUAL FUEL 456 #

TEST CONDITION	ERROR WARNING	COMPUTED FUEL #	ERROR	CLASS III ERROR LIMIT
All Probes Connected	0123	455	-1	10#
Probe #1 Disconnected	F123	450	-6	
Probe #2 Disconnected	1F23	451	-5	
Probe #3 Disconnected	12F3	456	0	
Probe #4 Disconnected	123F	455	-1	
All Probes Connected	0123	455	-1	

Tested By B Blanter Date 12/28 79

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FIGURE 14

ACOUSTIC NOISE TEST

	TEST POINT	20%	
TOP SURFACE	COMPUTED FUEL	START	264
	COMPUTED FUEL	DURING	264
	COMPUTED FUEL	AFTER	264
END SURFACE	COMPUTED FUEL	START	264
	COMPUTED FUEL	DURING	264
	COMPUTED FUEL	AFTER	264

FLUID TYPE test oil

TESTED BY B. Blauter

DATE 12/7 1979

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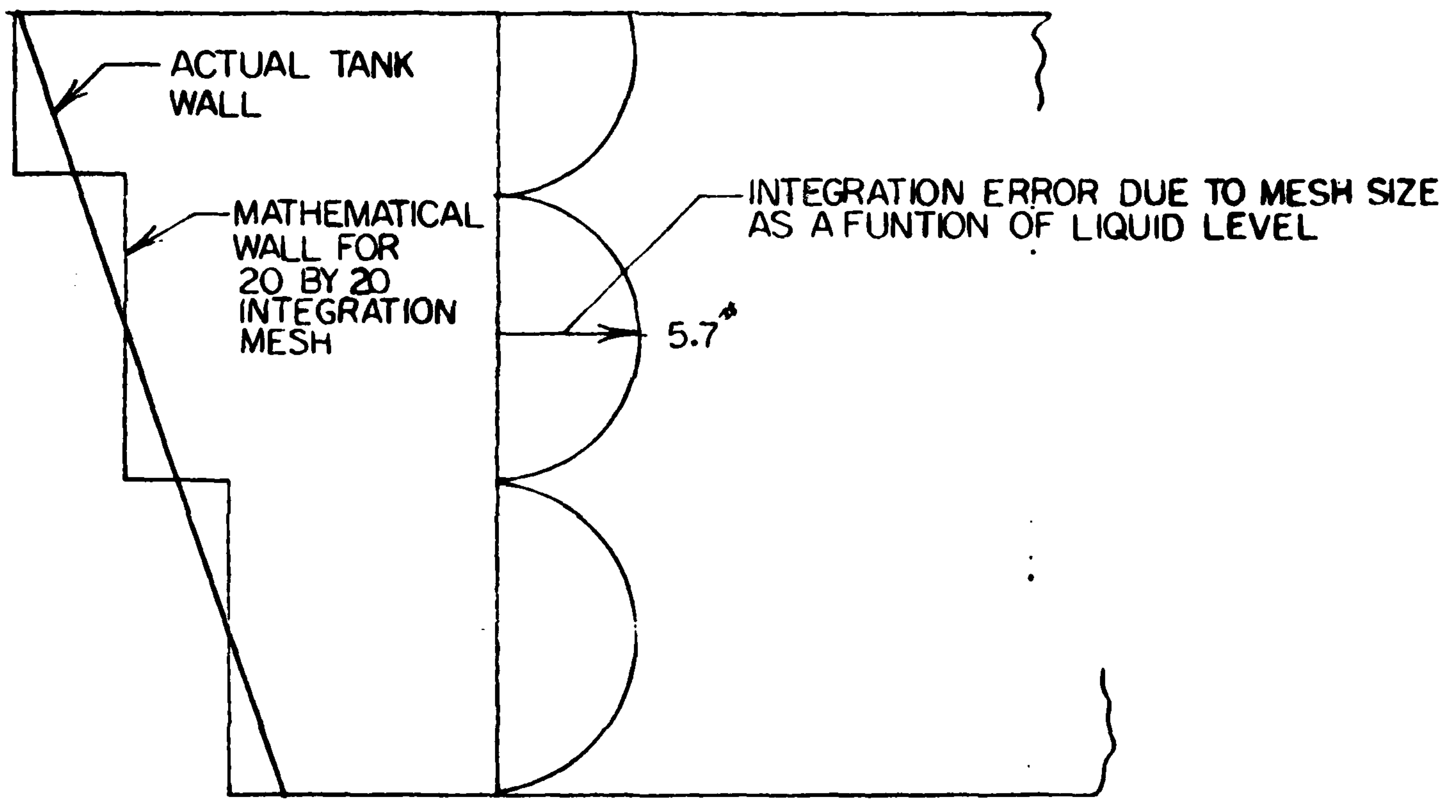

FIGURE 15

INTEGRATION ERROR SOURCE

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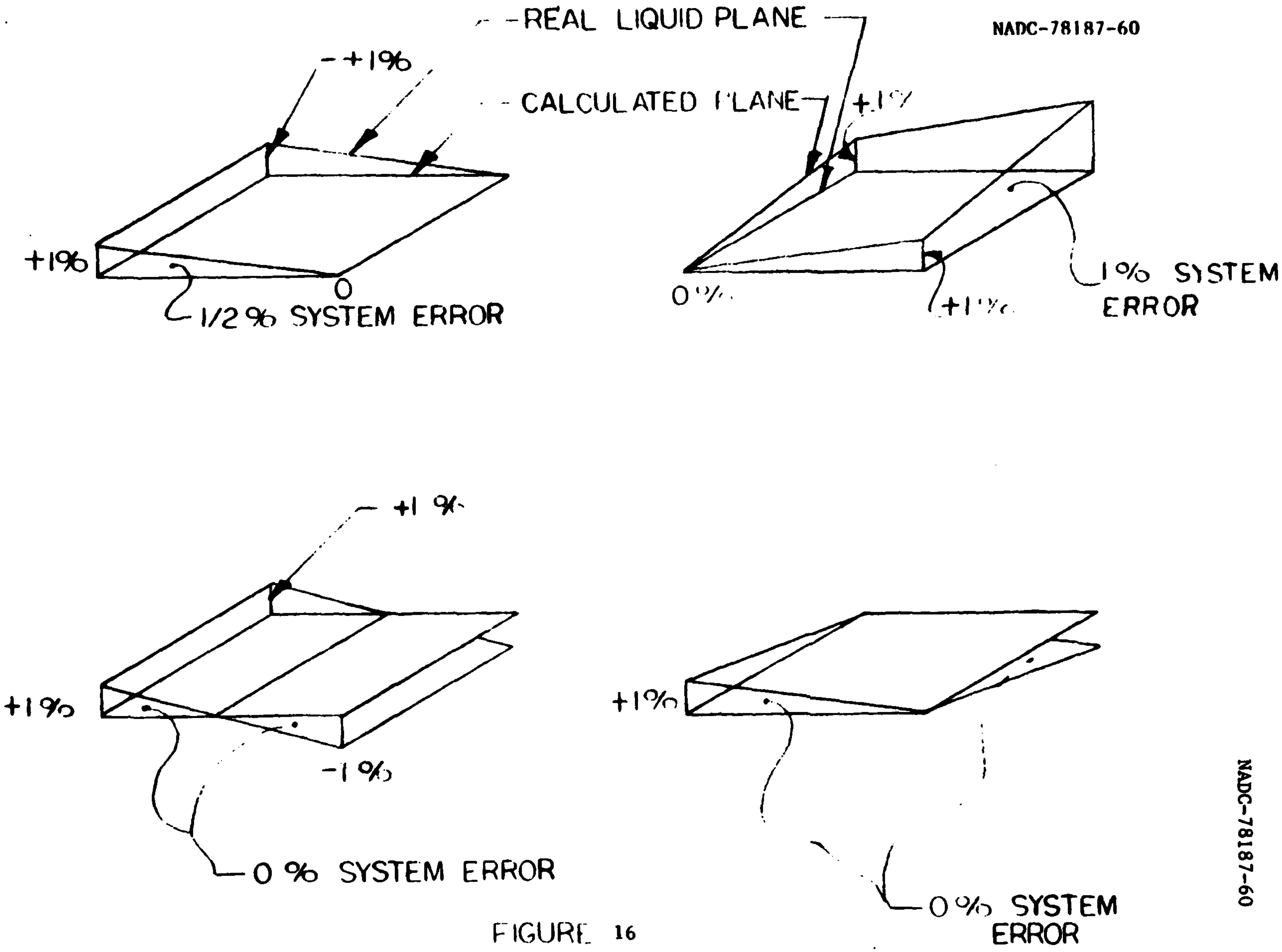

FIGURE 16

FOUR CASES WHERE 1% PROBE ERROR YIELDS A DIFFERENT SYSTEM ERROR

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APPENDIX A

Acoustic Fuel Quantity System Operating Instructions

(Laboratory Model)

A. General

The Acoustic Fuel Quantity System determines the mass of fuel contained in a test tank, for variable tank attitudes, fuel level and fuel density.

The Acoustic Fuel Quantity System consists of the following:

Four (4) Acoustic Liquid Level Probes (8TJ128)

One (1) Densitometer (8TJ129)

One (1) Laboratory Test Tank (A2412)

One (1) Interface Electronics Unit (IEU) (8KE108)

One (1) Signal Conditioning Unit (SCU) (A2426)

One (1) set of cables connecting the tank mounted sensors to the Interface Electronics Unit.

One (1) cable connecting the Interface Electronics Unit to the Signal Conditioning Unit.

The Signal Conditioning Unit controls the interrogation of the sensors via the Interface Electronics Unit, then receives the fuel height and density information from the sensors back through the Interface Electronics Units. It then processes this data to compute and display fuel mass or displays error messages resulting from sensor or other failures. The processor computes fuel mass by selecting the valid sensor outputs or estimates the fuel mass based on previous results.

B. System Characteristics

1. Power Requirements: 110-115 VAC, 30 VA (60-400 Hz)

2. Electrical Connections: As shown in Figure 1

3. Limitations:

   a. When the tank is near full the attitude should be limited so that the fuel does not touch the top surface of the tank, and/or cover the top portion of any probe.

   b. Measurements should be made at nominal room temperature ($68^{\circ}F$) for best accuracy.

   c. The connecting terminals on the Acoustic Probe should not be twisted when connecting or disconnecting cables.

C. Operation

1. General

   a. Connect all cables.

   b. Determine Operating Mode: The SCU can be operated in either of two modes:

      1) Mass computation mode: In this mode, the SCU computes mass and displays mass or errors. No intermediate data outputs are available.

      2) Manual Interrogation Mode: This mode allows the output of the sensors to be manually interrogated or the mass computed by typing proper instructions on the keyboard.

2. Detailed Operation

   a. Mass Computation Mode: (Under control of the user program after "power on"). For normal operation, remove the top

cover of the SCU and install PROM Chip labelled "A30" into socket labelled "A30" on the SDK-86 board. Install PROM Chip labelled "A27" into the socket labelled "A27" on the SDK-86 board. The display is read per Table 1.

b. Manual Interrogation Mode: (Under control of key pad monitor.)

Install key pad monitor PROMS marked 168-A30 and 167-A27 into sockets "A30" and "A27" respectively. To compute mass, punch "RESET", "GO", "F", "E", "0", "0", ":", "0", ".", and read out result as in example A above. To examine memory, select the address for the desired output from the following:

Output Desired	Desired Address (In Hex)
Probe 1 time delay in microseconds	30:6
Probe 2 time delay in microseconds	30:8
Probe 3 time delay in microseconds	30:A
Probe 4 time delay in microseconds	30:C
Densitometer Output	30:E

Punch the following sequence on the keyboard: "Interrupt", "EB", Desired Address, ",". Read out the contents of the memory on the display, which will be the least significant byte, in Hexidecimal, of the desired output. For the most significant byte, punch ",". For example, if the No. 1 probe time delay were required, the following sequence would be followed:

Punch On Keyboard:	"Interrupt", "EB", "30:6", ","
Display:	F6 (least significant byte)
Punch On Keyboard:	","
Display:	00 (most significant byte)
	The time delay for Probe No. 1 is thus equal to the decimal equivalent of 00F6 or 246 microseconds.

To rerun the program, computing mass only, the sequence starting with "RESET", "GO", etc., as shown before, would be followed.

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